TRANSMISSION CIRCUIT

BACKGROUND OF THE INVENTION

The present invention relates to circuits for transmitters of radio communications, below denoted as "transmission circuits".

In general, to process modulated signals with amplitude modulation, especially multiple modulation such as Quadrature Amplitude Modulation (QAM), radio-frequency power amplifiers in transmission circuits for transmitting power to antennas need linear amplification. Therefore, class A or AB had been adopted as operation classes of the RF power amplifiers.

However, with the progress of broadband communication, communication methods using subcarrier modulation such as Orthogonal Frequency Division Multiplex (OFDM) have come to be used and high efficiency is not expected any more with the conventional class-A or AB radio frequency amplifiers. That is, in the OFDM modulation, subcarriers are overlapped so that a large amount of power is instantaneously generated at random time and the ratio between the average power and the peak power, i.e., a Peak to Average Power Ratio (PAPR), is high. Therefore, a large amount of DC power always needs to be held in order to allow linear amplification of peak power which is much greater than the average power. With respect to class-A operation, the efficiency is only 50 % at the maximum. In particular, in the case of the OFDM modulation, since the PAPR is high, DC power obtained by multiplying current by the difference between the peak voltage for the peak power and the peak voltage for the peak power is lost in the form of heat in almost all the time except for the period in which the peak power is output. Accordingly, the resultant efficiency decreases largely.

As a result, wireless equipments using batteries as their power supplies, for

example, have shorter continuous operation time, and thus inconveniences arise in actual application.

To solve this problem, a conventional Envelope Elimination and Restoration (EER) technique known as Kahn Technique was proposed in FIG. **6** of U.S. Patent No. 6256482B1, for example.

FIG. **8** is a circuit block diagram showing a general concept of a known EER technique. In FIG. **8**, an OFDM modulated wave (modulated signal) generated by a modulator **401** is input to a detector **402**, which is a modulated signal detecting means, through a modulated signal line **410**. The detector **402** detects the OFDM modulated wave by dividing the wave into a phase component and an amplitude component. Specifically, the IQ carriers of the OFDM modulated wave generated by the modulator **401** are divided into an amplitude component $\sqrt{(I^2 + Q^2)}$ and a phase component $\tan^{-1}(Q/I)$ and these components are detected. The phase component (conjugated phase modulated wave) is transmitted from the detector **402** through phase component lines **411**, is up-converted by a phase component quadrature modulator **404**, and then is input to an RF input terminal of a PA **405** (RF power amplifier) in the form of RF signal power. The amplitude component (amplitude modulated wave) is transmitted through an amplitude component line **412**, is subjected to DC-to-DC conversion in a DC-to-DC converter **403**, and then is input to a power-supply-voltage terminal of the PA **405**.

Now, as an example of the OFDM modulated wave in the case of IEEE 802.11a, about 7 dB is needed as a backoff (the amount representing how much lower the output power is than the saturation power). That is, only 20 % of the RF peak power is used as the RF output power, so that the efficiency deteriorates from 50 % to 10 %. To use the class-A or AB PA with high efficiency, the minimum power-supply voltage required to output RF power is successively applied to the PA and the backoff is ideally 0 dB.

To solve this problem, in the EER technique, a modulated signal wave in which a quadrature modulation has been performed on a phase component obtained by polar mapping of a modulated signal is applied to the PA **405**. The modulated wave with this phase component is a sine wave whose amplitude is constant and whose phase changes with time, so that the PA **405** is operable with a backoff of almost 0 dB. As the output of the PA **405**, the amplitude component input from the power-supply-voltage terminal is multiplied by the phase component, so that the same modulated wave as that obtained by performing the quadrature modulation on the original modulated signal is obtained.

SUMMARY OF THE INVENTION

However, the known EER technique has a drawback in which the modulated signal wave is not restored correctly because the resultant spectrum mask or EVM (Error Vector Magnitude) does not satisfy the wireless standard in the response of the output voltage of the PA **405** with constant power applied thereto with respect to the power supply voltage thereof.

FIGS. **9A**, **9B** and **9C** are graphs respectively showing the voltage amplitude **Vin** of an amplitude component input to a power-supply-voltage terminal **VDD** of the conventional PA **405**, the response characteristic of an output voltage **RFout** with respect to an input voltage to the power-supply-voltage terminal **VDD** of the PA **405**, and the voltage amplitude of the output voltage **RFout** with respect to the voltage amplitude **Vin**. As shown in FIG. **9B**, the response of the PA **405** is a nonlinear response. Accordingly, if the EER technique is conducted, the phase component is multiplied by the amplitude component at the output of the PA **405**, so that an error in the amplitude component at 1V or less causes the EVM and the spectrum to deteriorate when a modulated signal wave is generated.

It is therefore an object of the present invention to provide a transmission circuit using an EER technique by which no signal deterioration occurs even with a PA exhibiting a nonlinear response.

As a basic configuration of a transmission circuit according to the present invention, at least an amplitude component of a modulated signal, which includes a phase component and the amplitude component, is detected, an amplitude component line for transmitting the amplitude component is provided, and judging means for judging whether or not an amplitude value of the amplitude component of the modulated signal is larger than a threshold value is provided on the amplitude component line.

With this configuration, it is possible to change a transmission method depending on the level of the amplitude component of the modulated signal, so that drawbacks of normal class-A operation and drawbacks in using an EER technique are suppressed. It is sufficient that the threshold value is set at a value corresponding to a boundary between the region in which a signal to be transmitted exhibits a linear response and the region in which the signal exhibits a nonlinear response. The linear response region is a region in which the linearity satisfies the spectrum mask and the EVM specified by the wireless standard under operation in which an appropriate offset voltage is applied to the response and the voltage amplitude component is multiplied by a constant of proportion such that the response range includes a voltage amplitude swing of the amplitude component of the modulated signal. The nonlinear response region is a region in which the linearity does not satisfy the wireless standard under the same operation. In this manner, it is possible to adopt a high-efficiency technique such as an EER technique in the region in which the signal to be transmitted satisfies the wireless standard, while adopting a technique capable of suppressing deterioration in the quality of the signal in the region in which the signal does not satisfy the wireless standard.

In the basic configuration described above, if the phase component as well as the amplitude component is detected and first selection outputting means for outputting the modulated signal to a modulated signal line if the amplitude value of the amplitude component is smaller than or equal to the threshold value and outputting the phase component to a phase component line for transmitting the phase component if the amplitude value is larger than the threshold value is provided, and second selection outputting means for outputting a constant voltage to a constant-voltage supply line if the amplitude value of the amplitude component is smaller than or equal to the threshold value and outputting the amplitude component to the amplitude component line if the amplitude value is larger than the threshold value is provided, then the outputs of the first and second selection output means are respectively connected to an RF input terminal and a power-supply-voltage terminal of an RF power amplifier. Accordingly, an EER technique is performed only in the region in which the response of the amplitude of the output from the RF output of the RF power amplifier satisfies the wireless standard and a usual modulation is performed in the region in which the response does not satisfy the wireless standard. As a result, it is possible to prevent signal deterioration that can be caused when EER is performed in the region in which the response of the RF power amplifier does not satisfy the wireless standard, thus implementing a transmission circuit with high efficiency and without deterioration of the signal to be transmitted.

The inventive transmission circuit may further include DC-to-DC converting means connected to the second selection outputting means and performing voltage conversion on an output signal from the second selection outputting means.

The inventive transmission circuit may further include means for specifying the level of output power to modulated signal generating means. Then, the output power level to be output is specified to the modulated signal generating means, so that the output power

level is arbitrarily set by setting the IQ level using the modulated signal generating means.

The inventive transmission circuit may further include frequency converting means disposed between the first selection outputting means and the RF power amplifier. Then, it is possible to process an RF signal covering a wider band. For example, since the DA converter handles signals with frequencies in the band of several hundreds MHz at most, the DA converter cannot process carriers whose frequencies exceed GHz. However, if the frequency converting means such as a quadrature converter is used, the carrier frequency is up-converted easily.

In addition to the basic configuration described above, the inventive transmission circuit may include selection outputting means for outputting a constant voltage to the constant-voltage supply line if the amplitude value of the amplitude component is smaller than or equal to the threshold value and outputting the amplitude component to the amplitude component line if the amplitude value is larger than the threshold value, depending on the judgment result of the judging means. Then, a pseudo-EER technique which is substantially the same as an EER technique is performed only in the region in which the response of the amplitude of the output from the RF output terminal of the RF power amplifier satisfies the wireless standard and a usual modification is performed in the region in which the response does not satisfy the wireless standard. As a result, it is possible to prevent signal deterioration that can be caused when EER is performed in the region in which the response of the RF power amplifier does not satisfy the wireless standard, thus implementing a transmission circuit with high efficiency and without deterioration of the signal to be transmitted.

In such a case, if frequency converting means is provided between the modulated signal generating means and the RF power amplifier, it is possible to process an RF signal covering a wider band. For example, since the DA converter handles signals with

frequencies in the band of several hundreds MHz at most, the DA converter cannot process carriers whose frequencies exceed GHz. However, if the frequency converting means such as a quadrature converter is used, the carrier frequency is up-converted easily.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit block diagram showing a transmission circuit according to a first embodiment of the present invention.

FIG. **2** is a diagram for describing an example of change of a signal processed in the transmission circuit of the first embodiment.

FIGS. **3A** and **3B** are graphs showing response characteristics of the voltages of output signals of RF amplifiers with respect to input voltages input to power-supply-voltage terminals of the RF amplifiers in a conventional transmission circuit and the transmission circuit of the first embodiment, respectively.

FIG. **4** is a circuit block diagram showing a transmission circuit according to a second embodiment of the present invention.

FIG. **5** is a circuit block diagram showing a transmission circuit according to a modified example of the second embodiment.

FIG. **6** is a diagram for describing an example of change of a signal processed in the transmission circuit of the second embodiment.

FIGS. **7A** through **7D** are diagrams for describing circuit operation in which a pseudo-EER technique is performed using a constant envelope region.

FIG. **8** is a circuit block diagram showing a general concept of a known EER technique.

FIGS. **9A**, **9B** and **9C** are graphs respectively showing the voltage amplitude **Vin** of an amplitude component input to a power-supply-voltage terminal of a conventional PA,

the response characteristic of an output voltage **RFout** with respect to an input voltage to the power-supply-voltage terminal, and the voltage amplitude of the output voltage **RFout** with respect to the voltage amplitude **Vin**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

EMBODIMENT 1

Hereinafter, a first embodiment of the present invention will be described with reference to the drawings. In this embodiment, OFDM is adopted for a modulation scheme. Examples of systems using OFDM are based on IEEE 802.11a standard, one of the wireless LAN standards. In a wireless LAN system, each of the 52 orthogonal subcarriers is modulated by, for example, 64 QAM, then an inverse discrete Fourier transform is conducted, and then each resultant carrier is multiplexed, thus obtaining an OFDM modulated signal. The 52 carriers are separated with a spacing of 312.5 kHz and occupy 52 × 312.5 = 16.25 MHz in total.

FIG. **1** is a circuit diagram showing a transmission circuit for implementing an EER technique according to the first embodiment. As shown in FIG. **1**, the transmission circuit includes: a modulated signal generator **101** as a modulated signal generating means for generating an OFDM modulated wave (modulated signal) including an amplitude component and a phase component; modulated signal lines **120** through which the OFDM modulated wave flows; a detector **102** as a modulated signal detecting means for detecting the amplitude component and the phase component of the OFDM modulated wave; phase component lines **121** for transmitting the phase component of the OFDM modulated wave; an amplitude component line **122** for transmitting the amplitude component of the OFDM modulated wave; a level judging circuit **106** as a judging means for judging whether the level of the amplitude component of the OFDM modulated wave is higher than a threshold

voltage level or not; a ROM **109** as a storage means for storing a threshold voltage level to be used as a reference for the level judgment of the level judging circuit **106**; a constant-voltage supply line **111** connected to a power-supply-voltage terminal at which a voltage of 1.1 V is received and used for supplying a constant voltage of 1.1 V; a first selector **103** as a first selection outputting means for selecting either one of the OFDM modulated wave from the modulated signal generator **101** and the phase component from the detector **102**, based on the judgment result of the level judgment circuit **106**; a signal selector **107** as a second selection outputting means for selecting either one of the amplitude component input through the amplitude component line **122** and the constant voltage of 1.1 V supplied through the constant voltage line **111**, based on the judgment result of the level judgment circuit **106**; a DC-to-DC converter **108**; a quadrature modulator **104** for performing a quadrature modulation on an output from the first selector **103**; and a PA **105** (RF amplifier) for receiving an RF signal output from the quadrature modulator **104** at its RF input terminal and receiving the amplitude component from the DC-to-DC converter **108** at its power-supply-voltage terminal; and a transmit power control section **110** for specifying output power to the modulated signal generator **101**.

The modulated signal generator **101** generates the above-described OFDM modulated wave (modulated signal). The OFDM modulated wave generated by the modulated signal generator **101** is input to the first selector **103** through the modulated signal lines **120**.

The detector **102** detects the OFDM modulated wave flowing through the modulated signal lines **120** by dividing the wave into a phase component (a conjugated phase modulated wave) and an amplitude component (an amplitude modulated wave). Specifically, the IQ vector wave of the OFDM modulated wave generated by the modulated signal generator **101** is divided into an amplitude component $\sqrt{(I^2 + Q^2)}$ and a

phase component $\tan^{-1}$ (Q/I) and these components are detected. The phase component is input to the first selector **103** through the phase component lines **121** as an IQ modulated wave, and the amplitude component is input to the second selector **107** through the amplitude component line **122**.

The level judging circuit **106** receives the threshold voltage level stored in the ROM **109** and the amplitude component flowing through the amplitude component line **122** and judges whether or not the voltage level of the amplitude component is higher than the threshold voltage level.

The first selector **103** selects and outputs one of the phase component of the OFDM modulated wave input through the phase component lines **121** and the OFDM modulated wave input through the modulated signal lines **120**, based on the judgment result of the level judging circuit **106**. At this time, if the voltage level of the amplitude component flowing through the amplitude component line **122** is lower than or equal to the threshold voltage level stored in the ROM **109**, the first selector **103** selects and outputs the OFDM modulated wave as a modulated signal, while selecting and outputting the phase component from the detector **102** if the voltage level of the amplitude component is higher than the threshold voltage level.

The second selector **107** selects and outputs one of the constant voltage of 1.1 V from the constant-voltage supply line **111** and the amplitude component input through the amplitude component line **122**, based on the judgment result of the level judging circuit **106**. At this time, if the voltage level of the amplitude component flowing through the amplitude component line **122** is lower than or equal to the threshold voltage level stored in the ROM **109**, the second selector **107** selects and outputs the constant voltage of 1.1 V from the constant-voltage supply line **111**, while selecting and outputting the amplitude component from the detector **102** if the voltage level of the amplitude component is higher

than the threshold voltage level.

The quadrature modulator **104** changes the conjugated phase modulated wave (Quadrature and In-phase) output from the first selector **103** into an RF signal.

The DC-to-DC converter **108** amplifies the output from the second selector **107** and supplies an amplitude modulated signal having a desired voltage amplitude to the power-supply-voltage terminal of the PA **105**.

The PA **105** is a class-A RF power amplifier and receives the RF signal output from the quadrature modulator **104** at its RF input terminal. When the system adopts an EER technique, the PA **105** receives the amplitude component subjected to DC conversion by the DC-to-DC converter **108** at its power-supply-voltage terminal. As a result, the PA **105** outputs a modulated wave whose phase and amplitude have been modulated, i.e., a modulated wave in which the amplitude is multiplied by the phase. If the system adopts a usual IQ quadrature modulation, the PA **105** fixes the voltage to be supplied from its power-supply-voltage terminal at 1.1 V to perform linear amplification.

The transmit power control section **110** receives specification regarding transmission power control from a Media Access Control (MAC) or other sections.

–Example of Signal Change in Processing–

FIG. **2** is a diagram for describing an example of change of a signal processed in the transmission circuit of this embodiment. FIGS. **3A** and **3B** are graphs showing response characteristics of the voltages of output signals **RFout** of the RF amplifiers **405** and **105** with respect to input voltages input to power-supply-voltage terminals of the RF amplifiers **405** and **105** in a conventional transmission circuit and the transmission circuit of this embodiment, respectively.

As shown in FIG. **2**, the output level specified by, for example, the MAC is input to

the modulated signal generator **101** via the transmit power control section **110** so that an IQ quadrature signal of an OFDM modulated wave exhibiting a constellation as shown in graph **2A** in FIG. **2** is generated in accordance with the output level. The OFDM modulated wave is detected by the detector **102**, being divided into an amplitude component shown in graph **2B** in FIG. **2** and a conjugated phase component (phase component) (not shown). The level judging circuit **106** compares the output amplitude component with the threshold voltage level set in the ROM **109** to judge whether or not the level of the amplitude component is higher than the threshold voltage level.

As shown in FIG. **3A**, for example, the threshold voltage level set in the ROM **109** is herein the minimum value, e.g., 1V, in a linear region in which the response characteristic between an input voltage of the RF power amplifier and the voltage of an output signal thereof exhibits a sufficient linear response. Alternatively, the threshold voltage level may be set by an appropriate formula manipulation. The linear region is herein the range in which an output spectrum or EVM (Error Vector Magnitude) of an output satisfies the wireless standard of communication systems, and does not mean that the response characteristic is a perfect linear characteristic.

The level judging circuit **106** judges whether the level of the amplitude component generated by the detector **102** is higher than the threshold voltage level (judgment **A**) or is lower than or equal to the threshold voltage level (judgment **B**), and outputs the judgment result **A** or **B** to the selectors **107** and **103**.

If the judgment **A** is input from the level judging circuit **106**, i.e., the amplitude component is in the state shown in graph **2C** in FIG. **2**, the second selector **107** selects the amplitude component (see graph **2E** in FIG. **2**) input from the detector **102** through the amplitude component line **122**, whereas the first selector **103** selects the phase component (see graph **2F** in FIG. **2**) input from the detector **102** through the phase component lines

121.

In this case, an EER technique is adopted in the transmission circuit. This EER technique allows the PA **105** to operate near a saturation point, i.e., to operate with the theoretical maximum efficiency. Accordingly, if the EER technique is performed, higher efficiency is achieved.

On the other hand, if the judgment **B** is input from the level judging circuit **106**, i.e., the amplitude component is in the state shown in graph **2D** in FIG. **2**, the first selector **103** selects the OFDM modulated wave (modulated signal) input from the modulated signal generator **101** through the modulated signal lines **120** and the second selector **107** selects the constant voltage of 1.1 V.

In this case, a usual IQ quadrature modulation is adopted in the transmission circuit. Accordingly, a small margin is added to the threshold voltage, which is herein set at 1V, and therefore the constant voltage to be supplied to the PA **105** is set at, for example, 1.1 V. Suppose the average voltage of a modulated wave having an amplitude of 1V or less is 0.8 V, the PA **105** operates with a backoff of about 2 dB. At this time, the efficiency is 31.5 %, which is 63 % of the theoretical efficiency in class-A operation of 50 %. Suppose operation of the PA **105** with the EER technique is saturation operation, a theoretical efficiency of 50 % is achieved. Accordingly, suppose the amplitude at the threshold voltage of 1 V or higher is about 10 %, the efficiency expected with the configuration of this embodiment is $50 \times 0.1 + 31.5 \times 0.9 = 33.4$ %.

On the other hand, if only the usual quadrature modulation is performed, an efficiency as small as 10 % is obtained. However, according to the present invention, the efficiency is greatly improved.

In a conventional transmission circuit, as shown in FIG. **3A**, a nonlinear region in which the wireless standard is not satisfied is present in the response characteristic of the

voltage amplitude at the RF output terminal **RFout** of the RF amplifier with respect to the voltage input to the power-supply-voltage terminal thereof, so that the output signal is distorted as shown in the left-part of FIG. **3A**. On the other hand, in this embodiment, an offset voltage applied to the amplitude component is appropriately adjusted in the DC-to-DC converter (where the offset voltage is 0.5 V in this embodiment) and, if the voltage level of the amplitude component is lower than or equal to the threshold voltage level, a usual quadrature modulation is performed. Accordingly, it is possible to make the entire response characteristic including 3A and 3B of the voltage amplitude at the terminal **RFout** with respect to the input voltage satisfies the wireless standard. As a result, the amplitude component is output without distortion as shown in the left-part of FIG. **3B**. As already described above, the linear region in this case also means that the resultant spectrum output from the power amplifier or EVM of the output satisfies the wireless standard of communication systems, and does not mean that the response characteristic is a perfect linear characteristic.

EMBODIMENT 2

In this embodiment, OFDM is also adopted for modulation. FIG. **4** is a circuit block diagram schematically showing a configuration of a transmission circuit according to a second embodiment of the present invention. As shown in FIG. **4**, the transmission circuit includes: a modulated signal generator **201** as a modulated signal generating means for generating an OFDM modulated wave (modulated signal) including an amplitude component and a phase component; modulated signal lines **220** through which the OFDM modulated wave flows; a detector **202** as a modulated signal detecting signal for detecting the amplitude component and the phase component of the OFDM modulated wave; an amplitude component line **222** for transmitting the amplitude component of the OFDM

modulated wave; a level judging circuit **206** as a judging means for judging whether the level of the amplitude is higher than a threshold voltage level or not; a ROM **209** as a storage means for storing a threshold voltage to be used as a reference for the level judgment of the level judging circuit **206**; a first DC-to-DC converter **208** provided on the amplitude component line **222** and performing DC-to-DC conversion on the amplitude component; a constant-voltage supply line **211** for supplying a constant voltage; a second DC-to-DC converter **210** interposed in the constant-voltage supply line **211** and performing DC-to-DC conversion on a constant voltage of 3 V to output a constant voltage of 1.1 V; a signal selector **207** as a selection outputting means for selecting either one of the amplitude component supplied from the first DC-to-DC converter **208** and the constant voltage of 1.1 V supplied from the second DC-to-DC converter **210**, based on the judgment result of the level judgment circuit **206**; a quadrature modulator **204** for performing a quadrature modulation on the OFDM modulated wave transmitted through the modulated signal lines **220**; and a PA **205** as an constant-saturation RF power amplifier for receiving an RF signal output from the quadrature modulator **204** at its RF input terminal and receiving the amplitude component from the selector **207** at its power-supply-voltage terminal.

In this embodiment, a circuit element having the same function as the transmit power control section **110** for specifying output power to the modulated signal generator **101** in the first embodiment may also be provided.

The constant-voltage supply line **211** is for supplying a constant voltage of 1.1 V converted by the second DC-to-DC converter **210**.

The detector **202** performs operation for obtaining the absolute value of a conjugated modulated vector of the modulated signal (OFDM modulated wave), thereby obtaining the amplitude component.

The level judging circuit **206** receives the threshold voltage level stored in the ROM **209** as a storage means and the amplitude component flowing on the amplitude component line **222** and judges whether or not the voltage level of the amplitude component is higher than the threshold voltage level.

The first DC-to-DC converter **208** amplifies the amplitude component input from the detector **202** through the amplitude component line **222** and supplies the amplitude component with a desired voltage amplitude to the power-supply-voltage terminal of the PA **205** and, at the same time, supplies a DC power required by the PA **205**.

The selector **207** selects and outputs one of the constant voltage of 1.1 V from the constant-voltage supply line **211** and the amplitude component input through the amplitude component line **222**, based on the judgment result of the level judging circuit **206**. At this time, if the voltage level of the amplitude component flowing on the amplitude component line **222** is lower than or equal to the threshold voltage level stored in the ROM **209**, the selector **207** selects and outputs the constant voltage of 1.1 V from the constant-voltage supply line **211**, while selecting and outputting the amplitude component output from the detector **202** through the first DC-to-DC converter **208** if the voltage level of the amplitude component is higher than the threshold voltage level.

The quadrature modulator **204** changes the OFDM wave (modulated wave), which is a conjugated phase modulated wave (Quadrature and In-phase) output from the detector **202**, into an RF signal.

The PA **205** as an RF power amplifier is a class-A amplifier and receives the RF signal output from the quadrature modulator **204** at its RF input terminal. When the system substantially adopts an EER technique, the PA **205** receives the amplitude component subjected to DC-to-DC conversion by the first DC-to-DC converter **208** at its power-supply-voltage terminal. As a result, the PA **205** outputs, from its RF output

terminal, a modulated wave whose phase and amplitude have been modulated, i.e., a modulated wave in which the amplitude is multiplied by the phase. If the system adopts a usual IQ quadrature modulation, the voltage supplied from the power-supply-voltage terminal of the PA **205** is fixed at the constant voltage of 1.1 V supplied from the constant-voltage supply line **211**.

−Example of Signal Change in Processing−

FIG. **6** is a diagram for describing an example of change of a signal processed in the transmission circuit of this embodiment.

As shown in FIG. **6**, the detector **202** detects an amplitude component as shown in graph **6B** in FIG. **6** from an OFDM modulated wave (conjugated vector signal) exhibiting a constellation as shown in graph **6A** in FIG. **6** and generated by the modulated signal generator **201**. The level judging circuit **206** compares the output amplitude component with the threshold voltage level set in the ROM **209** to judge whether or not the level of the amplitude component is higher than the threshold voltage level.

As shown in FIG. **3A**, for example, the threshold voltage level set in the ROM **209** is herein the minimum value, e.g., 1V, in a linear region in which the response characteristic between an input voltage of the RF power amplifier and the voltage of an output signal thereof exhibits a sufficient linear response. Alternatively, the threshold voltage level may be set by an appropriate formula manipulation. The linear region is herein the range in which an output spectrum or EVM of an output satisfies the wireless standard of communication systems, and does not mean the response characteristic is a perfect linear characteristic.

The level judging circuit **206** judges, using this threshold voltage level of 1V, whether the level of the amplitude component generated by the detector **202** is higher than

the threshold voltage level (judgment **C**) or is lower than or equal to the threshold voltage level (judgment **D**), and outputs the judgment result **C** or **D** to the selector **207**.

Unlike the first embodiment, in this embodiment, the modulated signal (OFDM modulated wave) generated by the modulated signal generator **201** is input to the RF input terminal of the PA **205** irrespective of whether the level judging circuit **206** outputs the judgment result **C** or **D** (see graph **6A** in FIG. **6**). The OFDM modulated wave is detected by the detector **202**, being divided into an amplitude component shown in graph **6B** in FIG. **6** and a conjugated phase component (phase component) (not shown). The level judging circuit **206** compares the output amplitude component with the threshold voltage level set in the ROM **209** to judge whether or not the level of the amplitude component is higher than the threshold voltage level.

If the judgment **C** is input from the level judging circuit **206**, the selector **207** selects the amplitude component input from the detector **202** through the amplitude component line **222** (see graph **6C** in FIG. **6**).

In this case, the input signal to the RF power amplifier is not a phase component as in the first embodiment but is a usual modulated wave having an amplitude component, and a pseudo-EER technique is adopted in the transmission circuit. Accordingly, this pseudo-EER technique allows the PA **205** to operate near a saturation point, i.e., to operate with the theoretical maximum efficiency. Operation by the pseudo-EER technique will be described in detail later.

On the other hand, if the judgment **D** is input from the level judging circuit **206**, the selector **207** selects the constant voltage of 1.1 V.

In this case, a usual IQ quadrature modulation is adopted in the transmission circuit. Accordingly, a small margin is added to the threshold voltage, which is herein set at 1V, and therefore the constant voltage to be supplied to the PA **205** is set at, for

example, 1.1 V. Suppose the average voltage of a modulated wave having an amplitude of 1V or less is 0.8 V, the PA **205** operates with a backoff of 2 dB. At this time, the efficiency is 31.5 %, which is 63 % of the theoretical efficiency in class-A operation of 50%. Suppose operation of the PA **205** with the EER technique is saturation operation, a theoretical efficiency of 50 % is achieved. Accordingly, suppose the amplitude at the threshold voltage of 1 V or higher is about 10 %, the efficiency expected with the configuration of this embodiment is $50 \times 0.1 + 31.5 \times 0.9 = 33.4$ %.

On the other hand, if only the usual quadrature modulation is performed, an efficiency as small as 10 % is obtained. However, according to the present invention, the efficiency is greatly improved.

In addition, in this embodiment, an EER technique is substantially performed with not the phase component but the modulated signal being input to the RF input terminal of the PA **205** without change. Accordingly, it is possible to avoid deterioration in Error Vector Magnitude (EVM), which is inevitable in known EER techniques by which only the phase component is input to the RF terminal of the RF power amplifier.

In a conventional transmission circuit, as shown in FIG. **3A**, a nonlinear region in which the wireless standard is not satisfied is present in the response characteristic of the voltage amplitude at the RF output terminal **RFout** of the RF power amplifier with respect to a voltage input to the power-supply-voltage terminal thereof, so that the output signal is distorted as shown in the left-part of FIG. **3A**. On the other hand, in this embodiment, an offset voltage applied to the amplitude component is appropriately adjusted in the DC-to-DC converter (where the offset voltage is 0.5 V in this embodiment) and, if the voltage level of the amplitude component is lower than or equal to the threshold voltage level, a usual quadrature modulation is performed. Accordingly, it is possible to make the entire response characteristic including 3A and 3B of the voltage amplitude at the terminal

RFout with respect to the input voltage satisfy the wireless standard as shown in FIG. **3B**. As a result, the amplitude component is output without distortion as shown in the left-part of FIG. **3B**. As already described above, the linear region in this case also means that the resultant spectrum output from the power amplifier or EVM of the output satisfies the wireless standard of communication systems, and does not mean that the response characteristic is a perfect linear characteristic.

Specifically, in a case where only the phase component is input to the RF input terminal of the RF power amplifier, filtering is performed on the phase component to an extent that would not affect the EVM within a range allowable in the band of a digital-to-analog converter. The partial decrease in the level of the phase component caused by this filtering greatly deteriorates the EVM when the phase component is synthesized with the amplitude component at the output of the RF power amplifier. In addition, the necessary bandwidth of the modulated signal is about 1/6 smaller than that of the phase component separated from the modulated signal, so that it is possible to narrow the bandwidth of a digital-to-analog converter or an anti-alias filter for suppressing spurious components generated by digital-to-analog conversion. Accordingly, this embodiment is effective for reduction of power consumption of a digital-to-analog converter, downsizing of an inductor used for the filter, and cost reduction.

In addition, in a conventional transmission circuit, the input power couples to the output depending on an isolation characteristic between the input and output of RF power to/from the RF power amplifier, so that an amplitude causing an error in the output of the RF power amplifier appears even when the amplitude component is zero. On the other hand, in this embodiment, when the amplitude component supplied to the power-supply-voltage terminal of the RF power amplifier is zero, the power input to the RF input terminal of the RF power amplifier is also zero. Accordingly, a correctly-modulated wave

is formed at the output of the RF power amplifier independently of the isolation characteristic.

FIGS. **7A** through **7D** are diagrams for describing circuit operation in which a pseudo-EER technique is performed using a constant envelope region.

The modulated wave (OFDM modulated wave in this embodiment) input to the RF power amplifier is herein a triangular wave in which the envelope of the amplitude is triangular as shown in FIG. **7A** for simplicity. FIG. **7B** shows the internal structure of the RF power amplifier. The RF power amplifier of this embodiment is comprised of a common emitter bipolar transistor. The OFDM modulated wave which is the modulated signal in this embodiment is input to the base (RF input terminal) of the bipolar transistor. This RF power amplifier is expressed by a simplified circuit in which a choke inductor is inserted between the collector (power-supply-voltage terminal) of the bipolar transistor and a terminal at which a collector voltage **Vc** is supplied and a line connecting the collector to the RF output terminal is grounded via an output load **ZL**.

FIG. **7D** is a graph for explaining an input-output characteristic of the RF power amplifier. The ordinate represents a collector current **Ic** of the RF power amplifier and the abscissa represents the collector voltage **Vc** applied to the power-supply-voltage terminal of the RF power amplifier. FIG. **7D** shows that the Ic-Vc characteristic changes with respect to the base-emitter voltage **Vbe** of the RF power amplifier and that a load line, which is determined by the DC base-emitter voltage **Vbe**, the DC current collector voltage **Vc** and the output load **ZL** of the RF power amplifier, determines the variable range of the base-emitter voltage **Vbe** and also determines the variable ranges of the collector current **Ic** and the collector voltage **Vc**.

FIG. **7C** shows the resultant output voltage from the RF output terminal of the RF power amplifier. The output power is determined by this output voltage and the output

impedance **ZL**.

When the input voltage exceeds the variable range (Vbe4-Vbe2 in FIG. **7D**) of the base-emitter voltage **Vbe**, the corrector current exceeds the variable range of the collector current **Ic** determined by the load line, thus creating a (constant envelope) time region in which the current amplitude is constant. The voltage amplitude is obtained by voltage conversion performed on the collector current **Ic** with the load impedance **ZL** at the output, so that a constant (constant envelope) time region is also created in the voltage amplitude **Vout** (=Ic · ZL). A signal having a constant envelope region is substantially equivalent to a phase component, so that the same processing is performed in function as in EER in which the phase component and the amplitude component are respectively input to the RF input terminal and the power-supply-voltage terminal of the RF power amplifier. Therefore, this processing is herein referred to as a pseudo-EER technique.

In this embodiment, in a time region (region where the wireless standard is satisfied) in which the pseudo-EER technique is used, the threshold voltage in the level judging circuit is set such that the output voltage exhibits a constant envelope, or the input voltage is adjusted such that a saturated output current is obtained in a period in which the pseudo-EER technique is performed. In this manner, power amplification with the pseudo-EER technique is performed when the amplitude component of the modulated signal is higher than the threshold voltage in the level judging circuit.

—Modified Example of Embodiment 2—

FIG. **5** is a circuit block diagram schematically showing a configuration of a transmission circuit according to a modified example of the second embodiment. As in the transmission circuit of the second embodiment shown in FIG. **4**, the transmission circuit of this modified example also includes: a modulated signal generator **201**; a detector **202**; a

quadrature modulator **204**; a PA **205**; modulated signal lines **220**; and an amplitude component line **222**. Basic functions of these circuit elements are the same as those described in the second embodiment.

In this modified example, one DC-to-DC converter **211** is provided and a selector **207** in which a DA converter is incorporated is interposed between the detector **202** and the DC-to-DC converter **211**. A threshold voltage level of 1.1 V stored in a ROM **209** as a storage means is supplied to an RF input terminal of the selector **207** through a constant-voltage supply line **251**. Specifically, in this modified example, the threshold voltage level to be compared with the voltage level of an amplitude component by a level judging circuit **206** is equal to the level of a constant voltage that is input from the constant-voltage supply line **251** to a power-supply-voltage terminal of the PA **205** via the selector **207**. That is, the ROM **209** serves as a means for storing the threshold voltage level as well as a means for supplying the constant voltage to the power-supply-voltage terminal of the PA **205** in the region in which the wireless standard is not satisfied.

Modulating operation in this modified example is basically the same as in the second embodiment, so that the same effects as in the second embodiment are obtained. In addition, in this modified example, only one DC-to-DC converter is sufficient, so that the modified example is more advantageous than the second embodiment in terms of cost reduction. Further, the selector is disposed upstream from the DC-to-DC converter, so that this modified example has another advantage of being able to use a transmitter with a relatively low breakdown voltage as long as the DC-to-DC converter also has an amplifying function.

In particular, the pseudo-EER technique used in the second embodiment or the modified example thereof has an advantage that a low EVM is maintained in a wide band, as compared to the first embodiment. However, the efficiency is enhanced more easily

with the method of the first embodiment using the EER technique than with the second embodiment and the modified example thereof.

Now, a device for implementing the transmission circuits of the first and second embodiments and the modified example of the second embodiment will be described.

The modulated signal generator, the detector and the level judging circuit may be mounted on one LSI chip. In this case, the other circuit elements are provided on another LSI chip or discrete chips.

The frequency converting means (e.g., the quadrature converter **104** or **204**) is not necessarily provided. But the provision of the quadrature converter **104** or **204** allows a high-frequency signal in a wider band to be used. For example, since the DA converter handles signals with frequencies in the band of several hundreds MHz at most, the DA converter cannot process carriers whose frequencies exceed GHz. However, if the frequency converting means is used, the carrier frequency is up-converted easily.

The frequency converting means such as the quadrature modulator is preferably provided on an LSI chip on which the modulated signal generator, the detector and the level judging circuit are mounted.

The DC-to-DC converter, the selector, the RF power amplifier and the ROM may be individually provided on respective discrete chips for a transmission circuit, or may be provided within a chip on which the modulated signal generator, the detector and the level judging circuit are mounted, as a system LSI. In such a case, one or more circuit elements out of the DC-to-DC converter, the selector, the RF power amplifier and the ROM can be provided on a chip on which the modulated signal generator, the detector and the level judging circuit are mounted.

The ROM for storing the threshold voltage level is not necessarily provided. Alternatively, a signal indicating the threshold voltage level may be input from outside.

The means for inputting the constant voltage to the constant-voltage supply line may be a voltage generator provided on an LSI chip or may be a member for supplying a voltage to the power-supply-voltage terminal from outside.

The transmission circuit according to the present invention is applicable as a transmission section of wireless communication apparatus such as cellular phones and wireless LANs.